ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Thermal Circulation Patterns and Turbulent Fluxes along Steep Mountain Slopes

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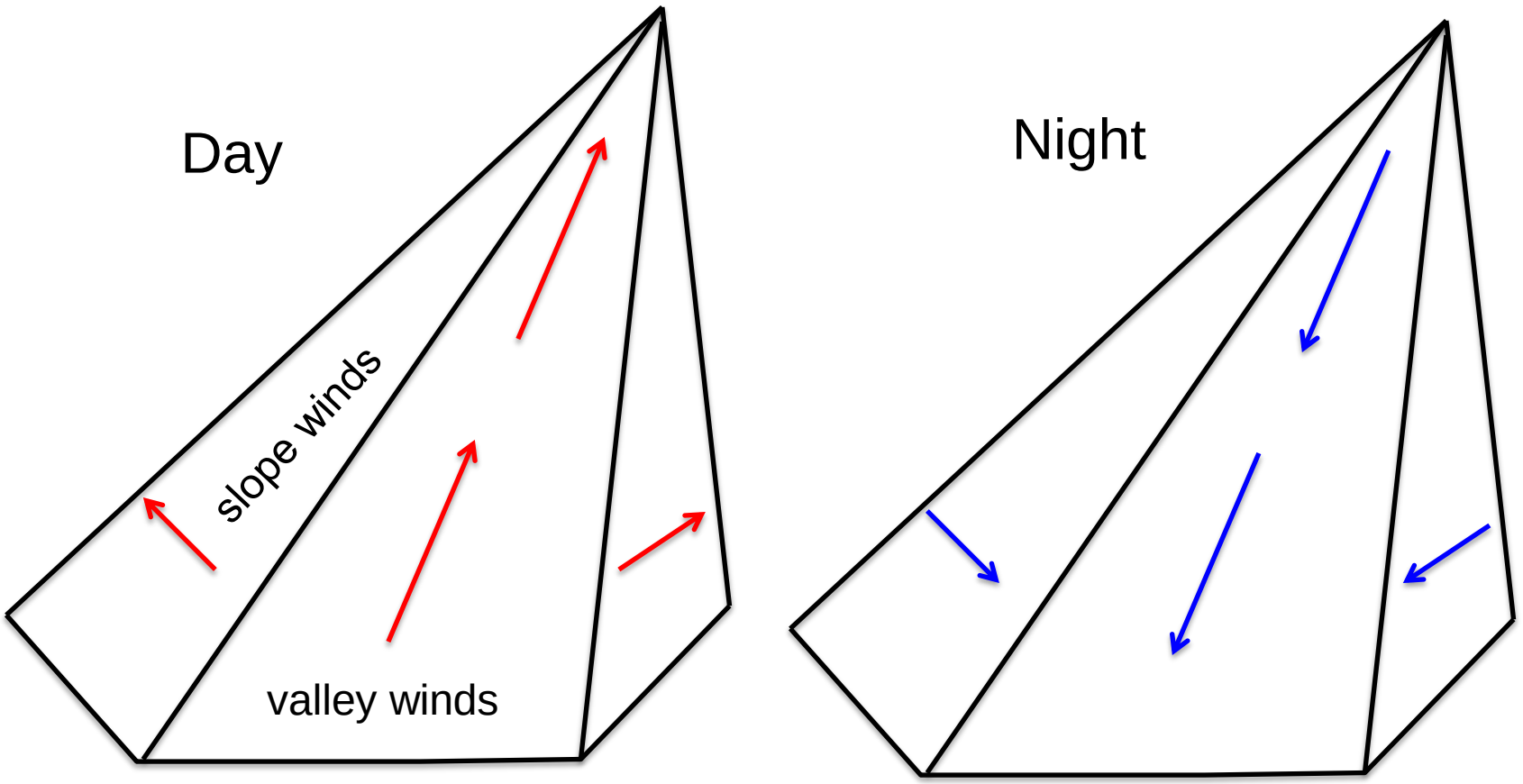
60% of Switzerland’s surface
is covered with mountains
How well do we understand thermal atmospheric circulations
over this complex terrain?

Introduction

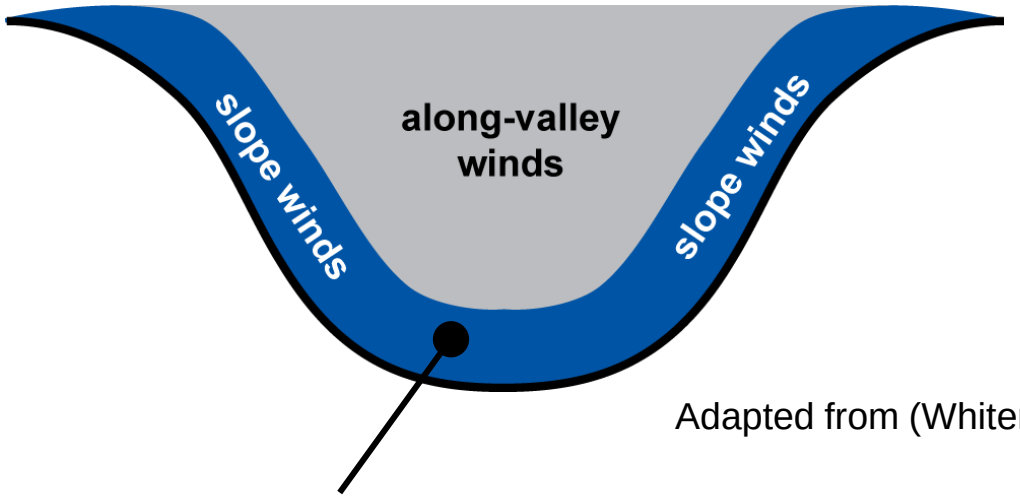
Under clear sky conditions in summertime



Adapted from (Whiteman, 2000)

Introduction

Vertical structure of diurnal mountain winds



Adapted from (Whiteman, 2000)

Land-atmosphere interactions take place in this layer.

Understanding slope winds is crucial for hydrological models.

Motivations

What we know:

- basic atmospheric circulations are well understood
- theory and literature are mostly focused on gentle terrain and idealized slopes
- some important field campaigns to study mountain winds:
    - MAP experiment
    - T-REX
    - Mt. Hymettos (Greece)

Challenges:

- thermal circulations are unsteady
- lack of theory and understanding during transition periods
- hard to monitor meteorological processes over steep terrain

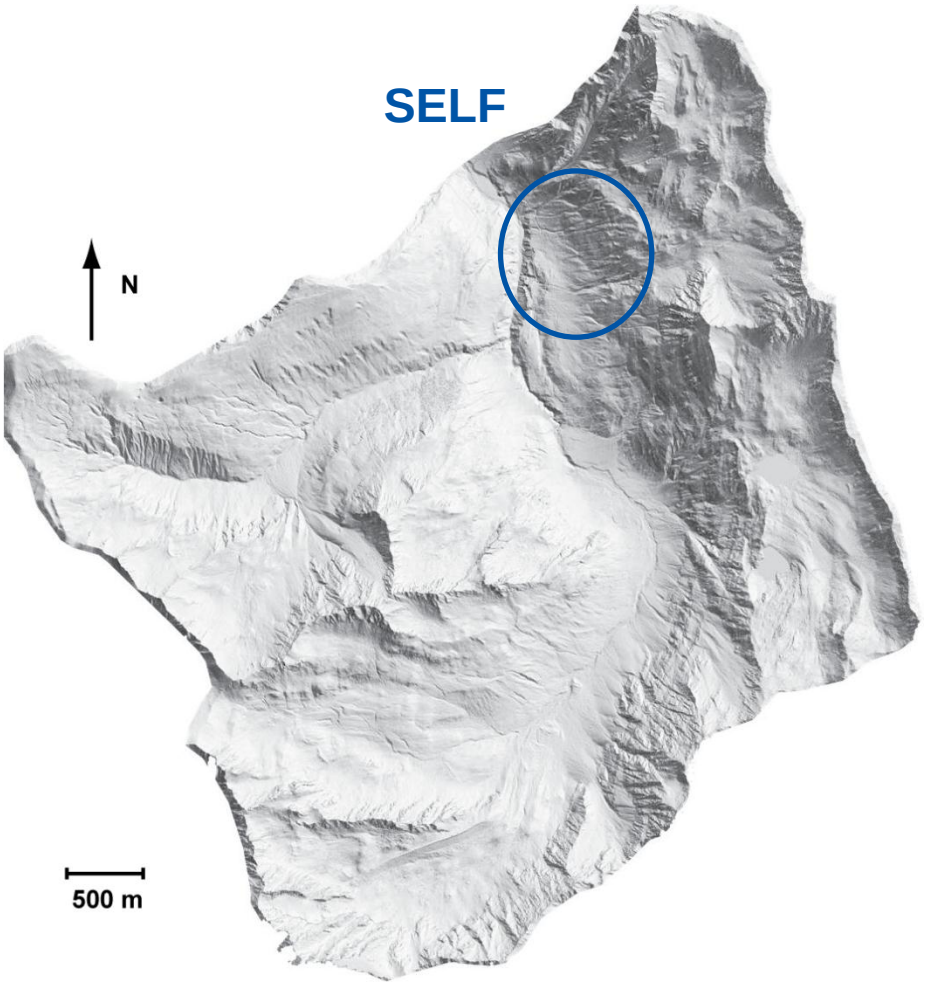
Open questions:

- time scales during evening transitions?
- transitioning front, from top to bottom or vice-versa?
- atmospheric response to abrupt shut-off of solar radiation?

Experimental Site

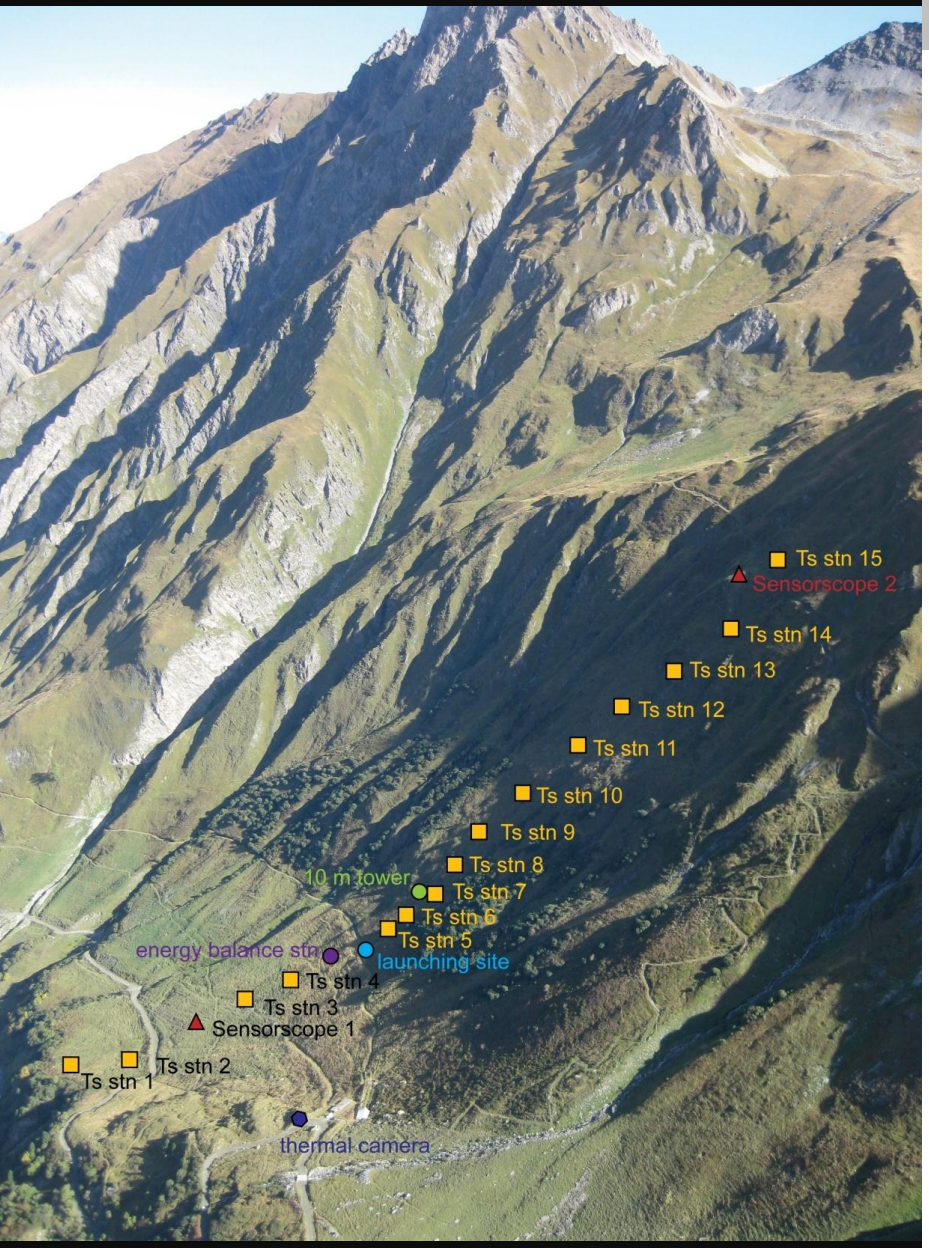
Slope Experiment at La Fouly (SELF)

Dranse de Ferret Alpine Catchment



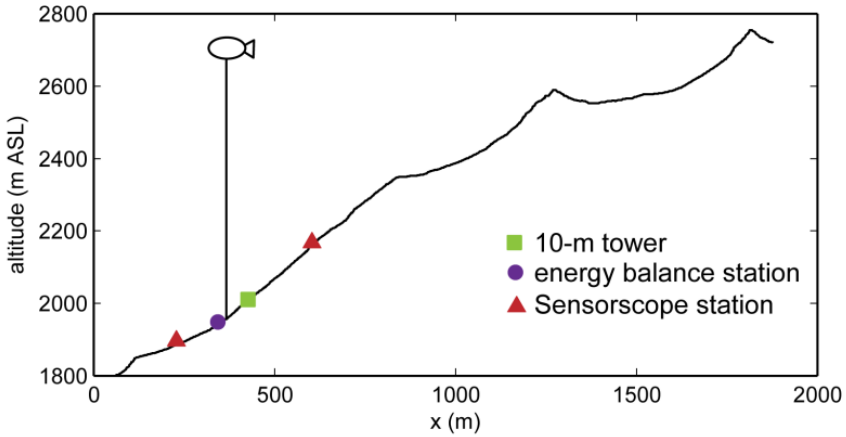
Val Ferret, Swiss Alps
45.902°N, 7.123°E
7 July to 30 Sept. 2010
West-facing slope (25° to 45°)
Instruments: from 1900 to 2200 m ASL

Experimental Setup



21 Sept. 2010, 09:45

- T_{sfc} stations
- thermal camera (during IOPs)
- energy balance station
- 10 m tower
- tethered balloon (during IOPs)
- Sensorscope stations



T_{sfc} Measurements

undergrad student

deployed during 2 IOPs (clear-sky days):

- infrared camera FLIR A320 (320 x 240 px)
- optical camera (752 x 480 px)

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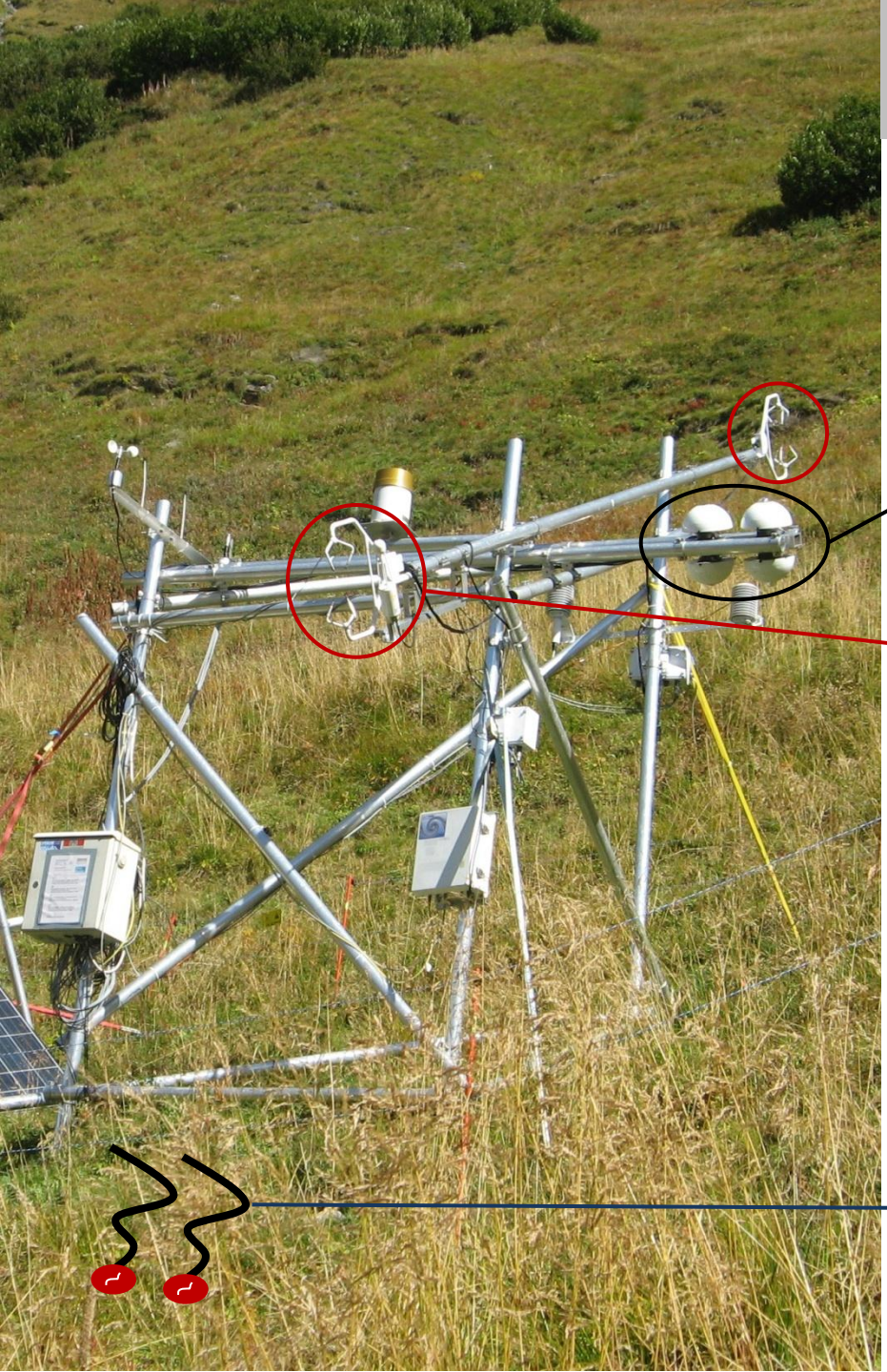
sampling frequency: 7 Hz

surface temperature stations

(Zytemp TN901 IR sensors with Arduino boards)

Energy Balance Station (slope: 30°)

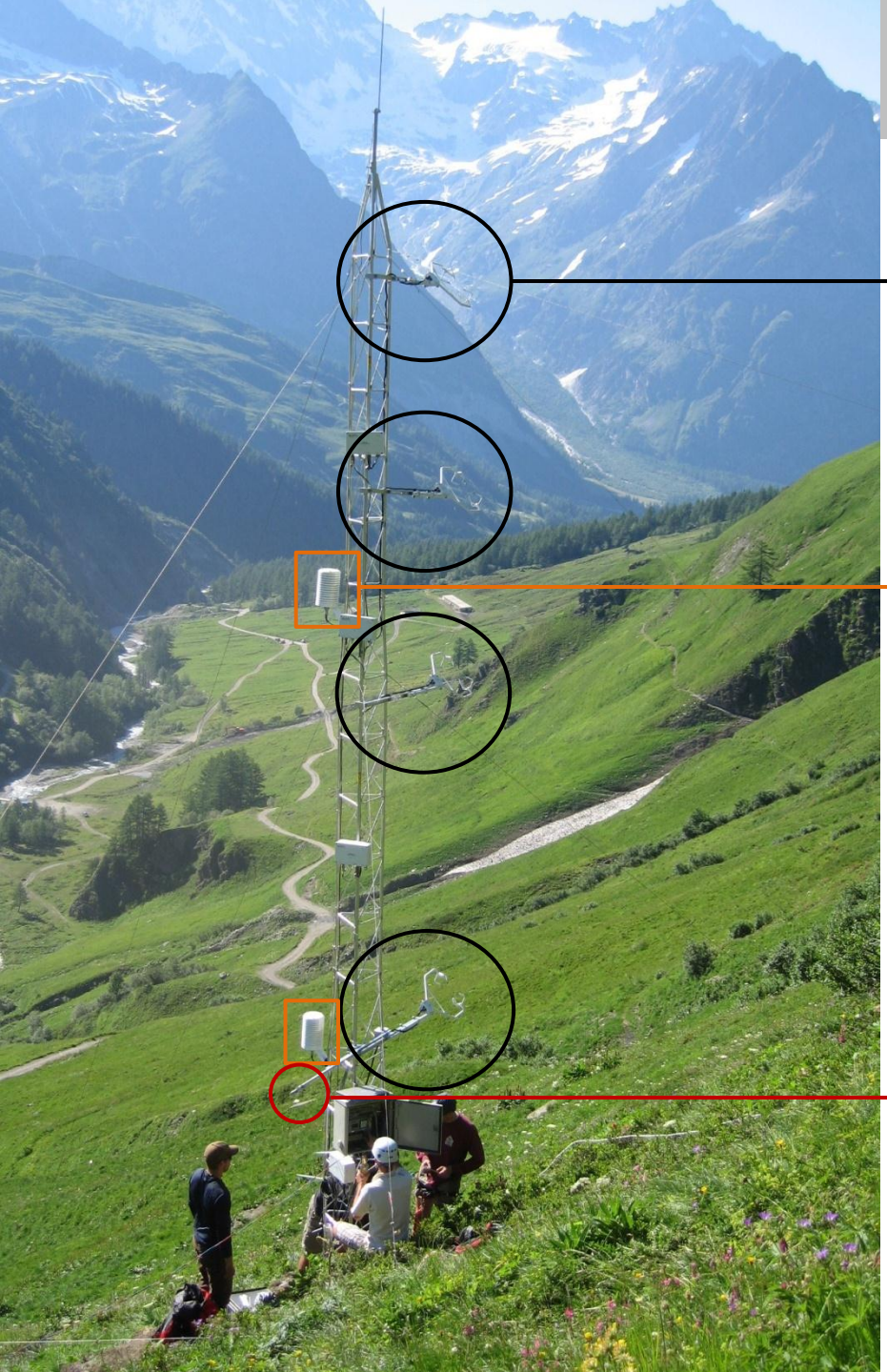


4 radiometers (LW↑, LW↓, SW↑,SW↓)
(mounted parallel to the slope)

1 open path H_2O-CO_2 analyzer
2 sonic anemometers
(axis normal to the slope)
⇨ planar fit correction

2 soil heat flux plates

10-m Tower (slope: 42°)



4 sonic anemometers
(axis normal to the slope)
⇨ planar fit correction

2 T + RH sensors

1 net radiometer
(axis normal to the slope)

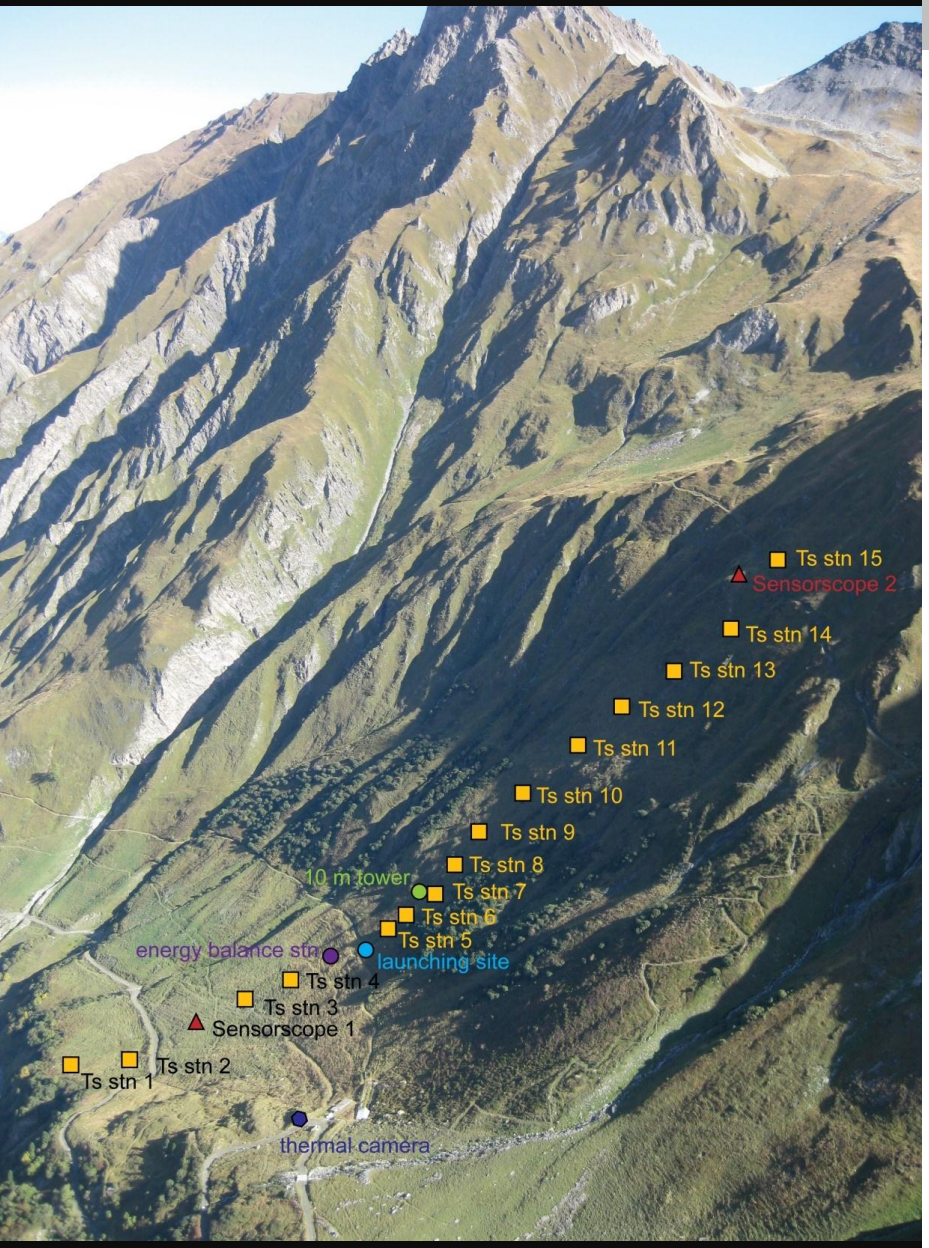
Tethered Sonde

- deployed during 4 IOPs (clear-sky days)
- measurements of:
  - wind speed
  - wind direction
  - air temperature
  - relative humidity
- profiles from 0 to 750 m above ground (1950 to 2700) m ASL

Sensorscope Stations

- wireless network of weather stations
- measurements of:
  - wind speed
  - wind direction
  - air temperature
  - surface temperature
  - relative humidity
  - solar radiation
  - soil moisture
- 2 stations installed on the slope
- 15 stations in the entire catchment

Experimental Setup



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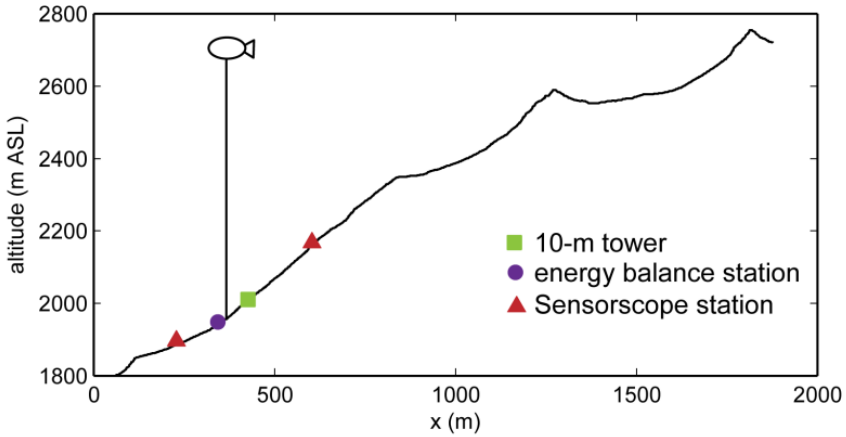
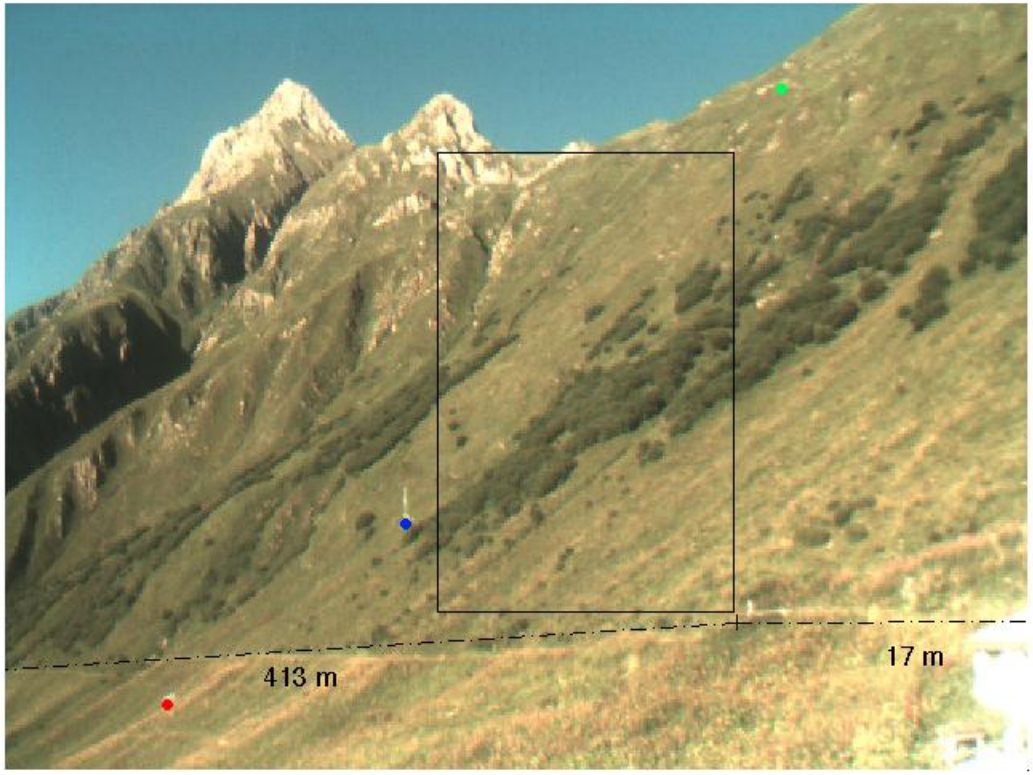
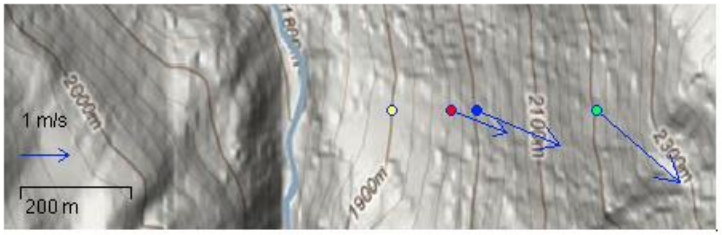
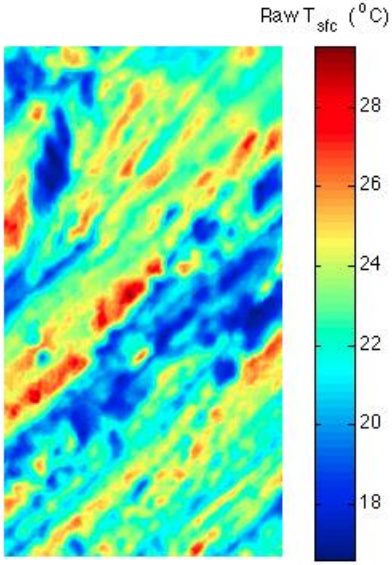


1 September 2010:
The Story of an Evening Transition

Val Ferret: 01-Sep-2010 18:00:25

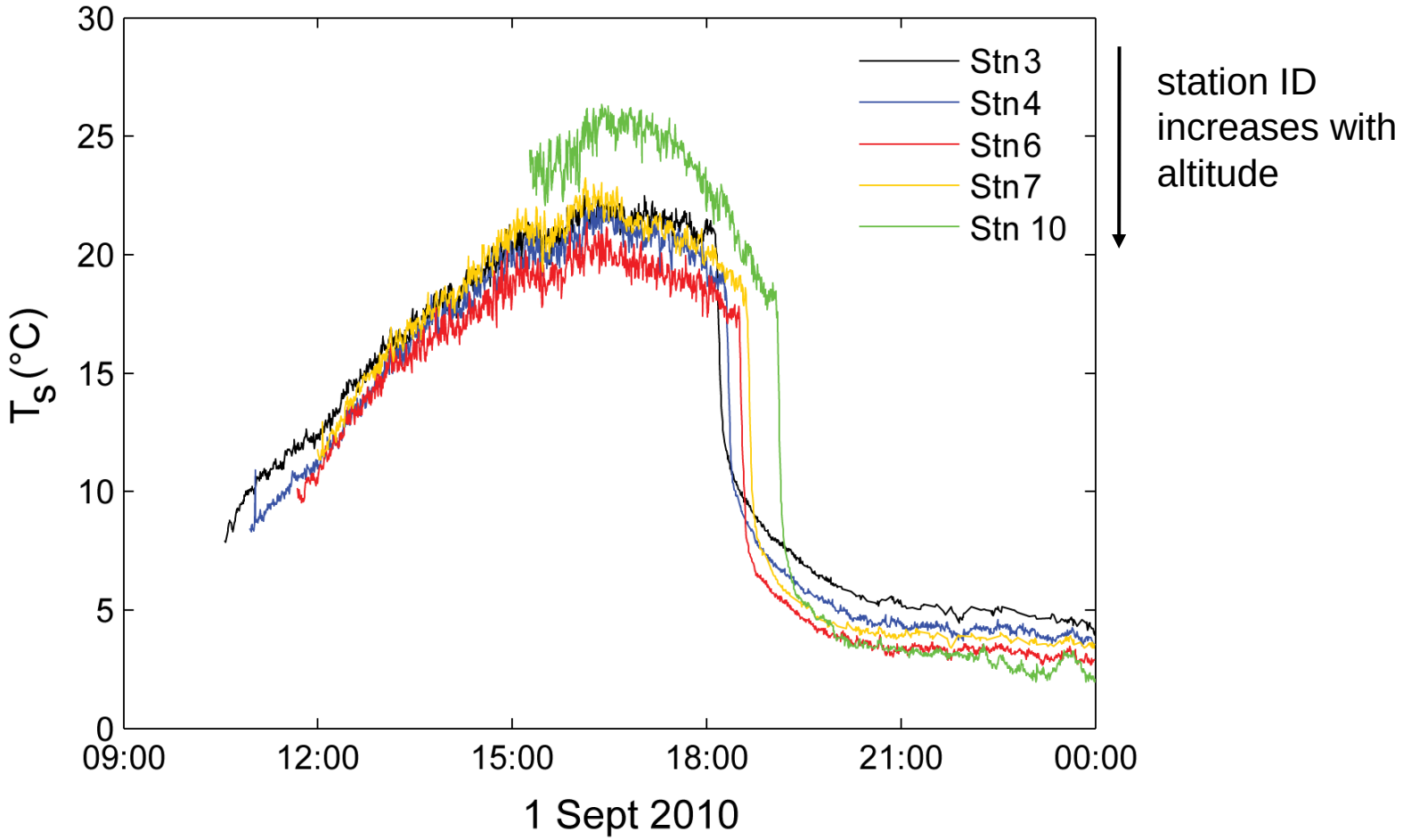






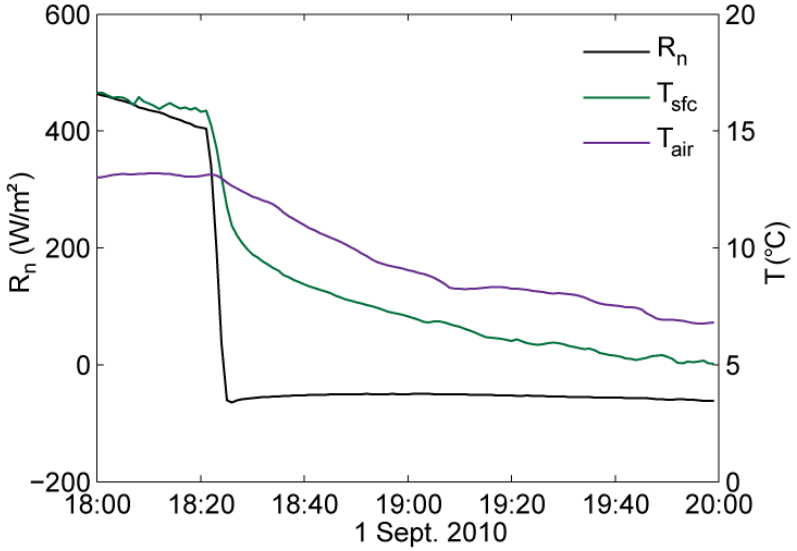
Surface's Response at Transition

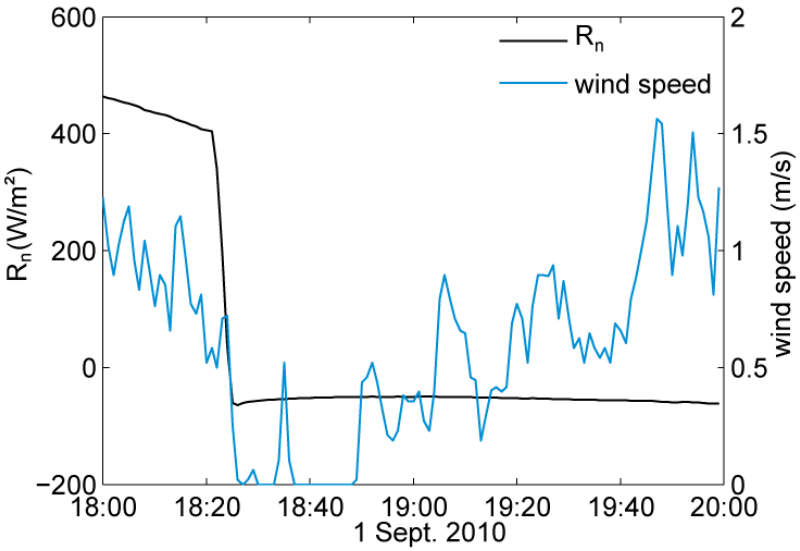
- bottom of the valley is shaded first
- dramatic drop in surface temperature when shade sets in

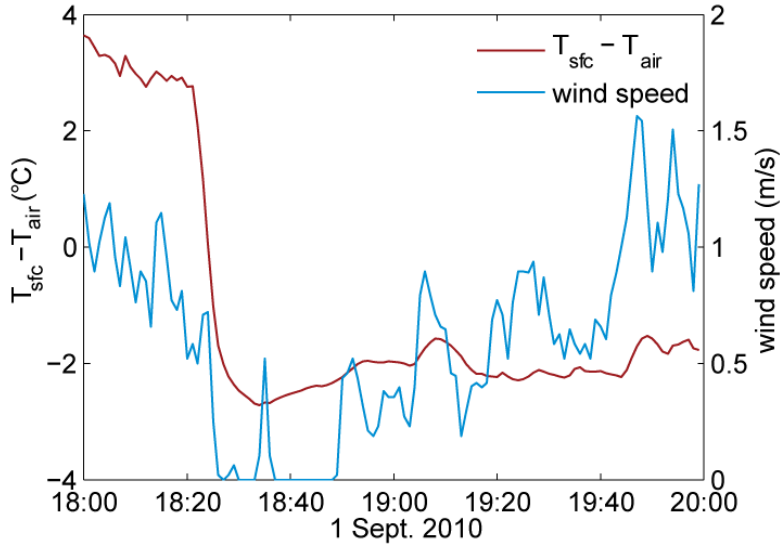


Atmospheric Response at Transition

Measurements at the energy balance station



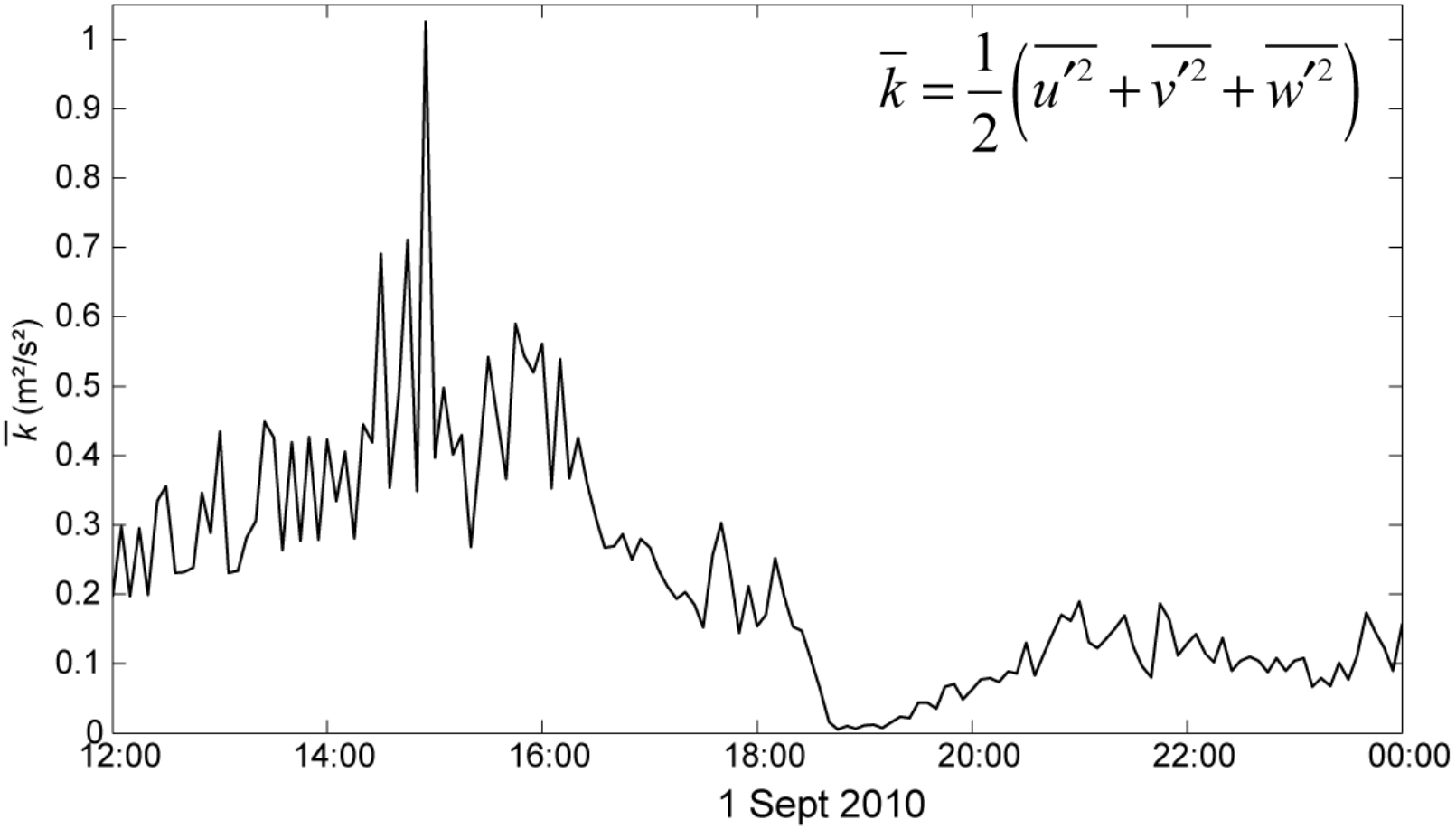




- quick response of T_{sfc}
- winds go to 0 m/s
- stratification builds up
- winds flow downslope

Turbulent Kinetic Energy (k)

Measurements from the lowest sonic (z = 1.5 m) at the 10-m tower



Turbulent Kinetic Energy Balance (dk/dt)

$$\frac{\partial \bar{k}}{\partial t} = \frac{g}{\bar{\theta}_v}\left(\overline{w'\theta_v'}\right) - \overline{u'w'}\frac{\partial \bar{U}}{\partial z} - \frac{\partial\left(\overline{w'k}\right)}{\partial z} - \frac{1}{\bar{\rho}}\frac{\partial\left(\overline{w'p'}\right)}{\partial z} - \varepsilon$$

neglect

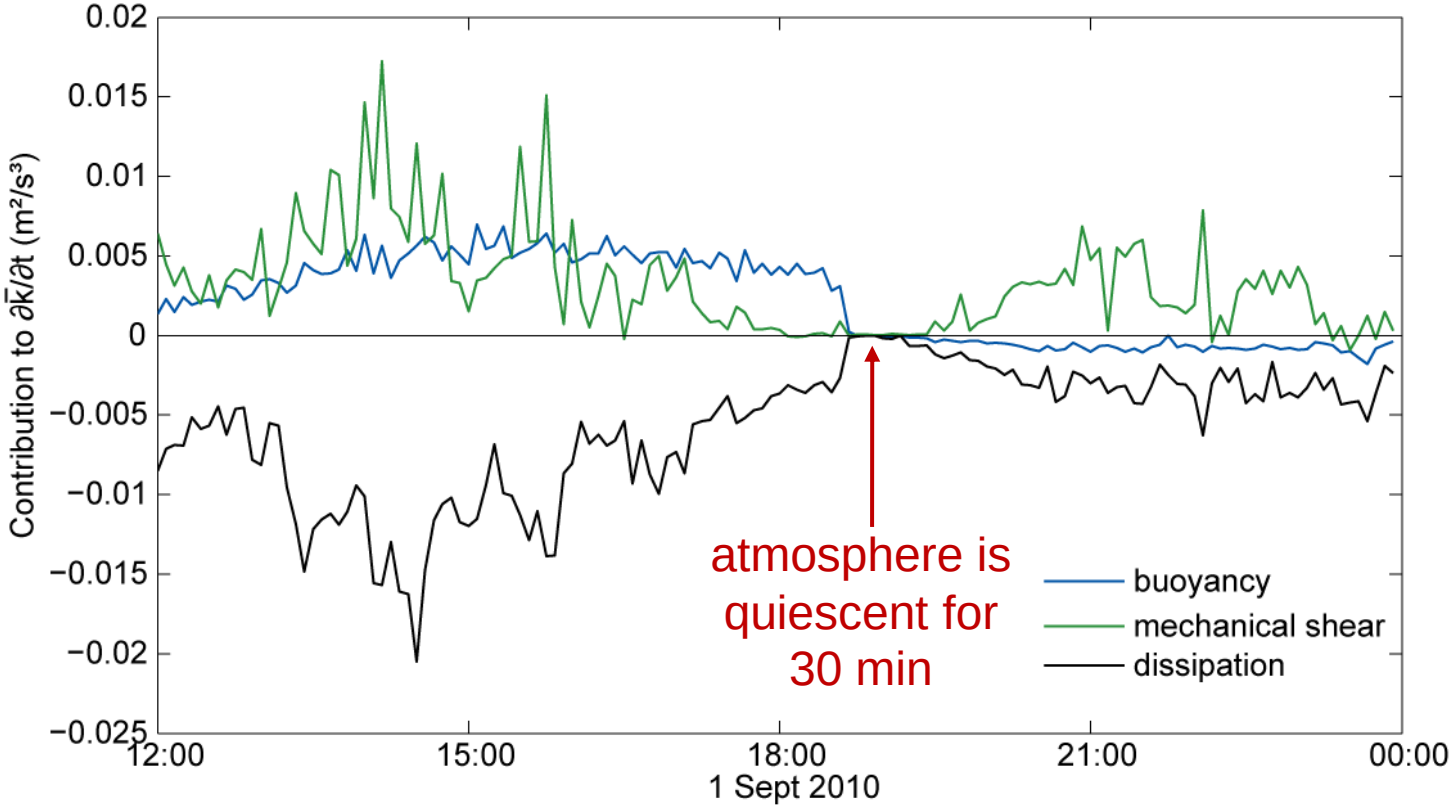
buoyancy

mechanical shear

dissipation

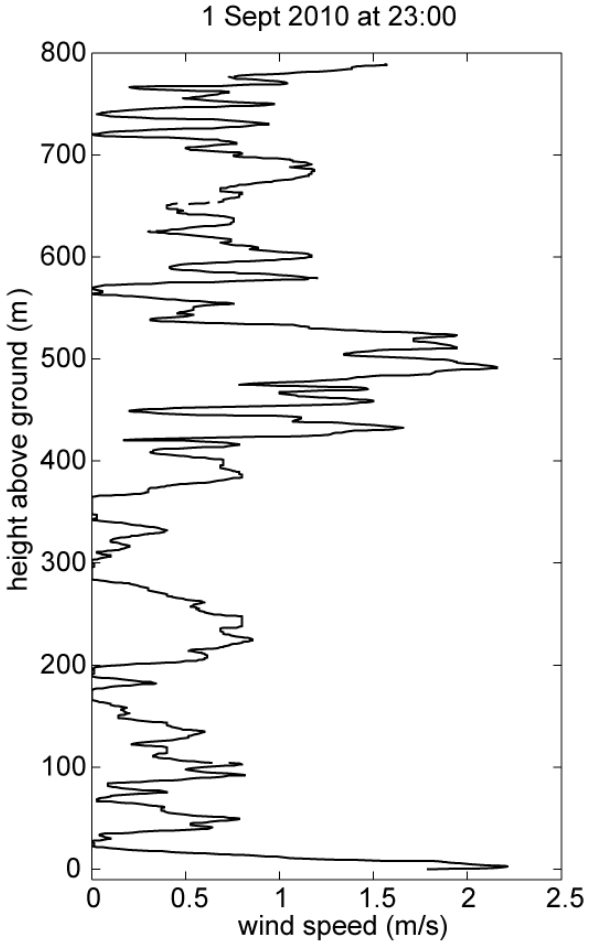
$$\varepsilon = 0.3634\left(r^{-1}\right)\left(D_{uu}\left(r\right)\right)^{3/2}$$

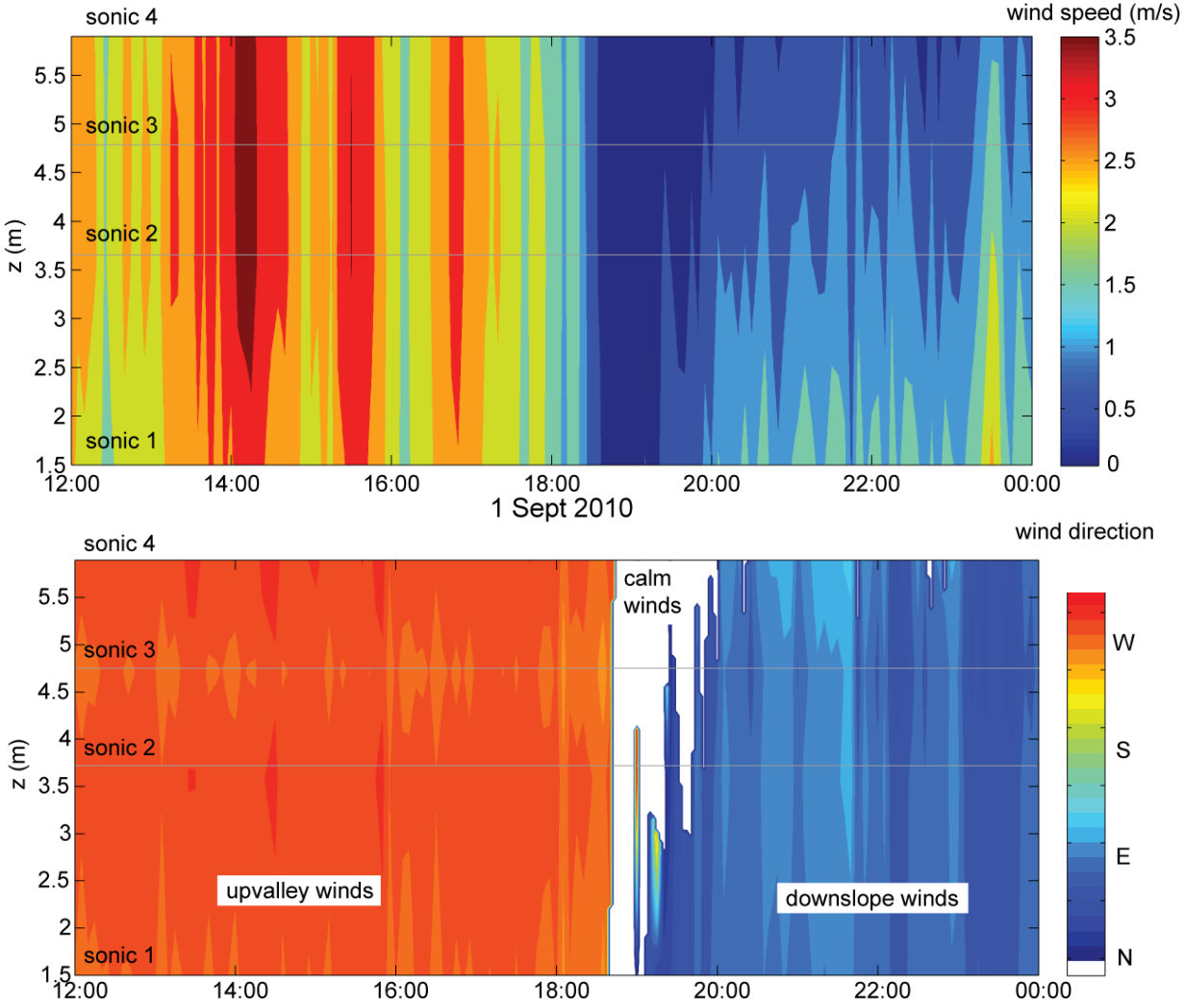
Measurements from the lowest sonic (z = 1.5 m) at the 10-m tower



Nighttime Skin Flow

Measurements from the 10-m tower





Conclusions

Evening transition in three steps

1) T_{sfc} reacts dramatically to rapid decrease in R_n
2) Atmosphere is quiescent for 30 min.
3) Build-up of stratification leads to very shallow downslope winds (skin flow)

Future work

- Generalize approach for radiative days (ensemble means)
- Define important physical scales

Acknowledgements

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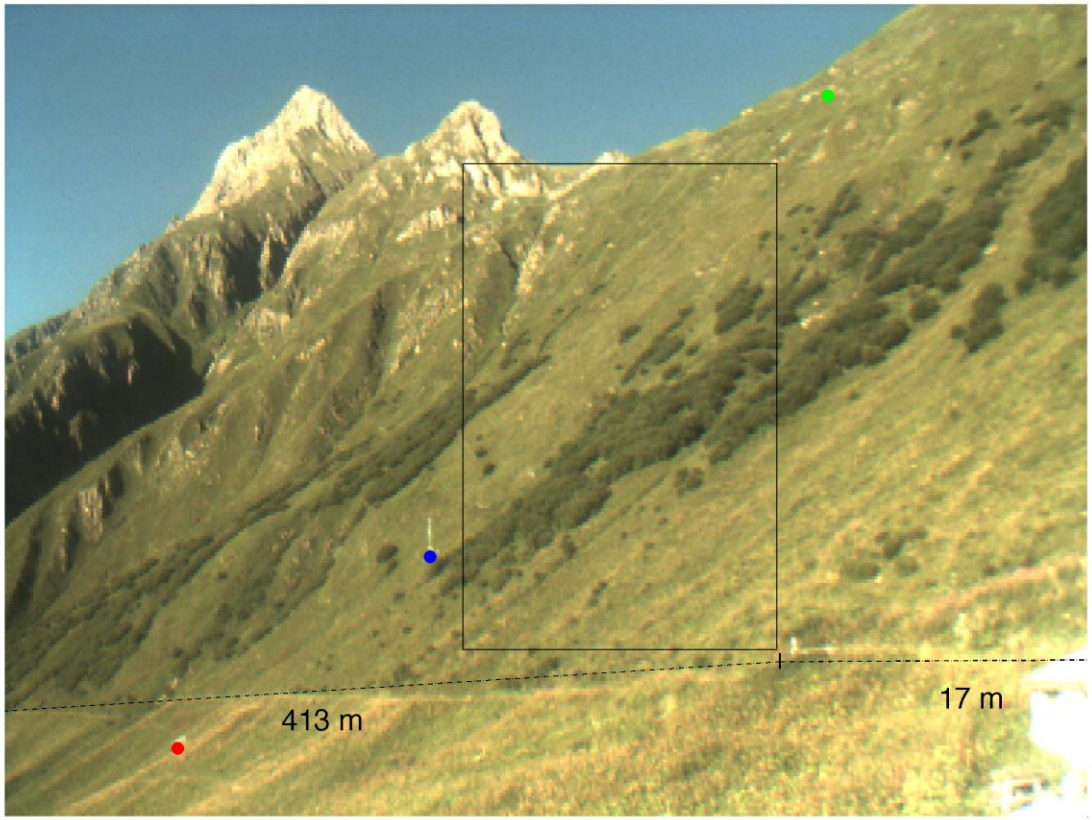
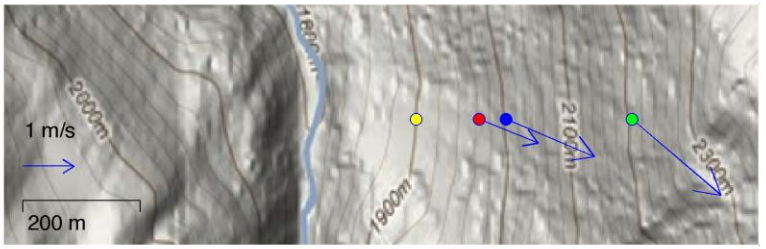
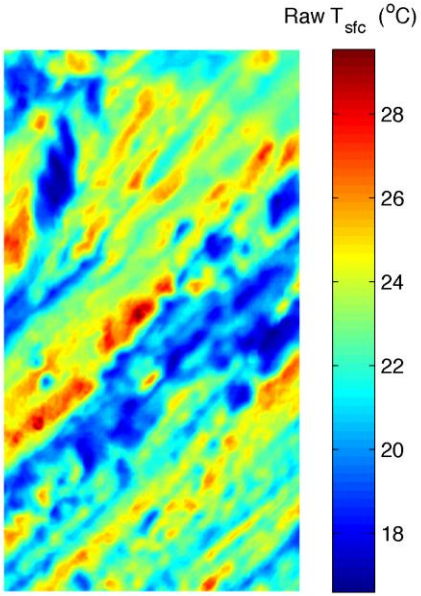
Thank you!

Val Ferret: 01-Sep-2010 18:00:25







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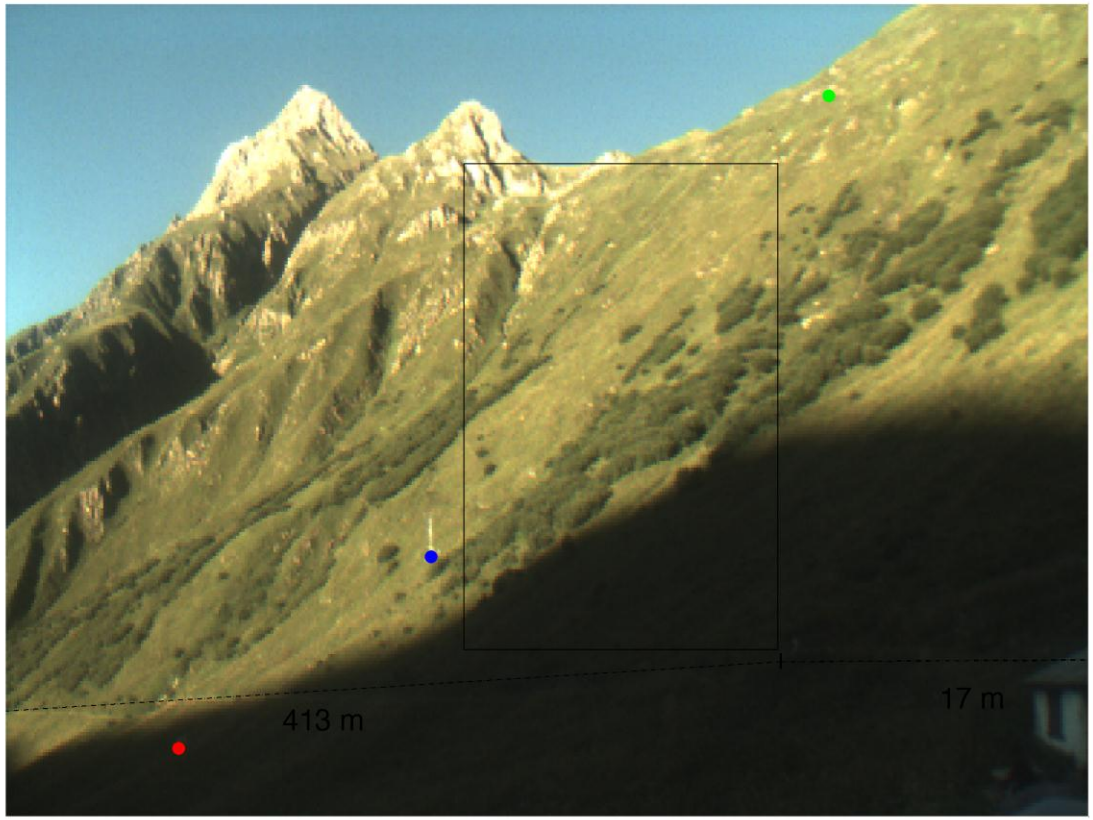

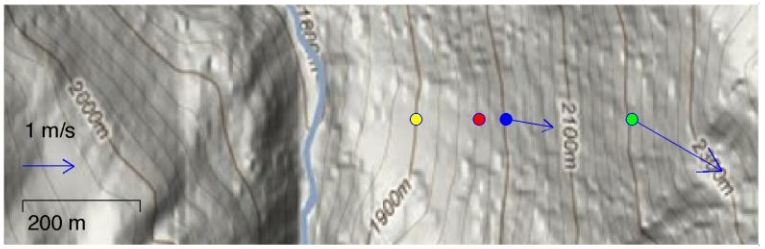

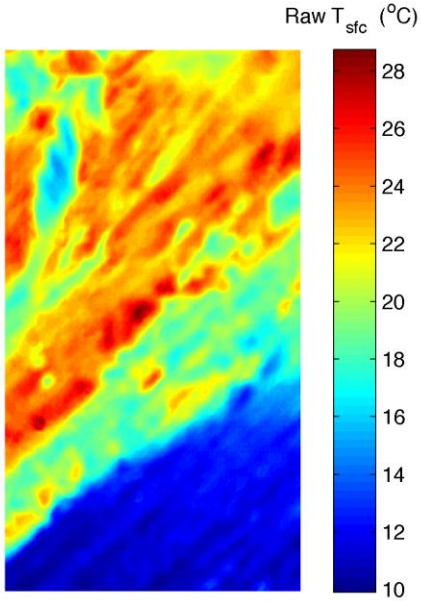

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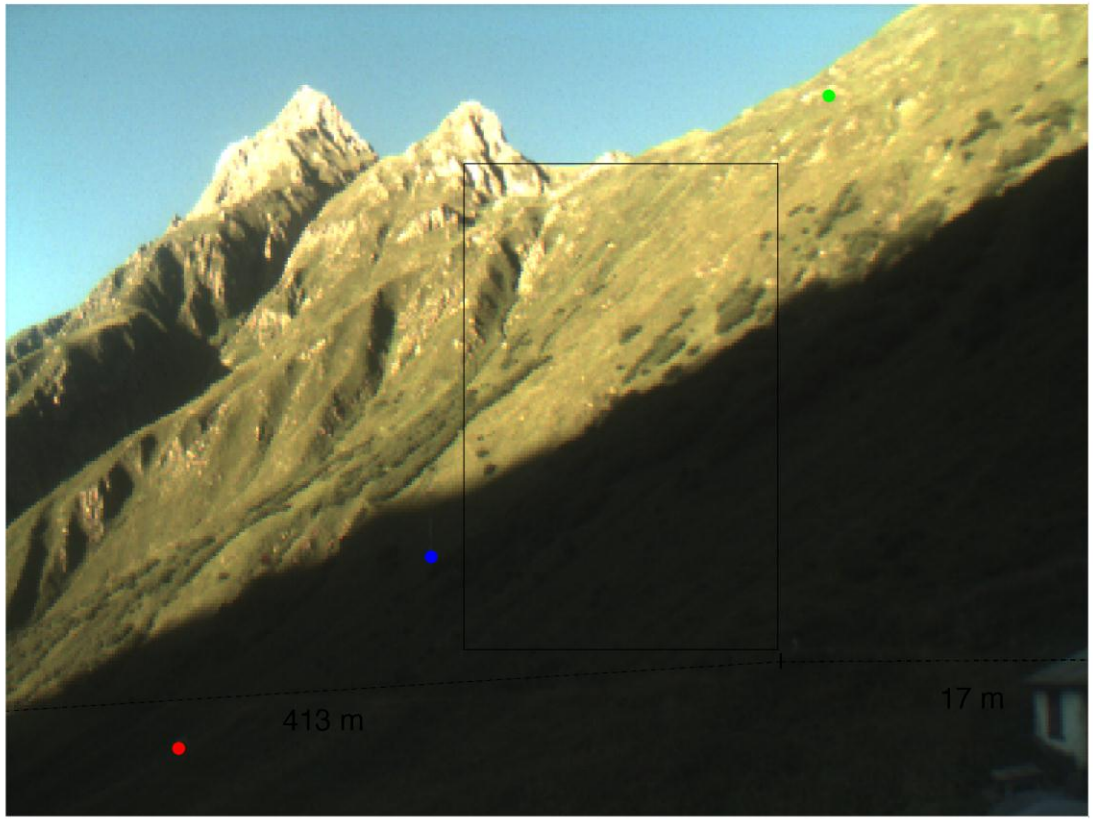

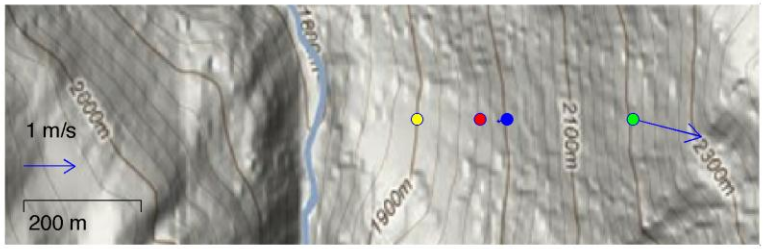

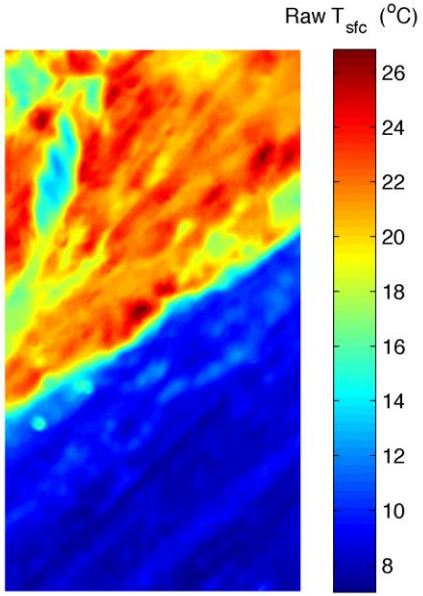

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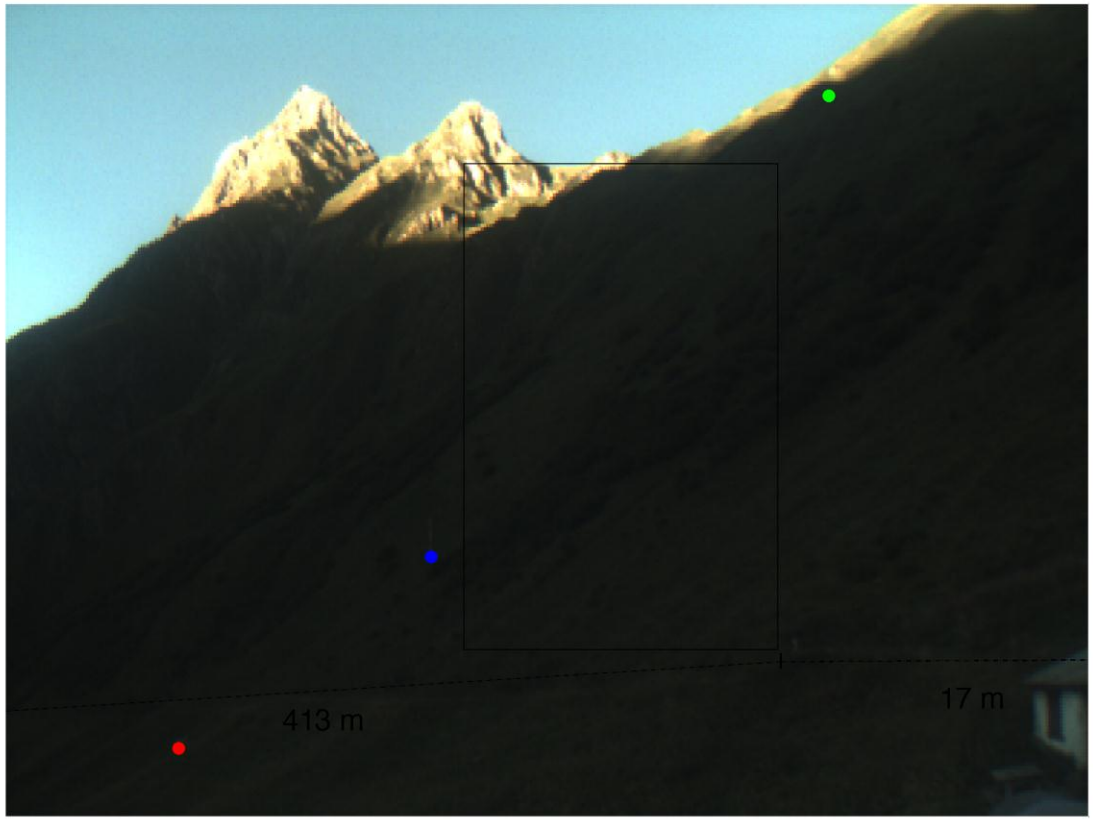

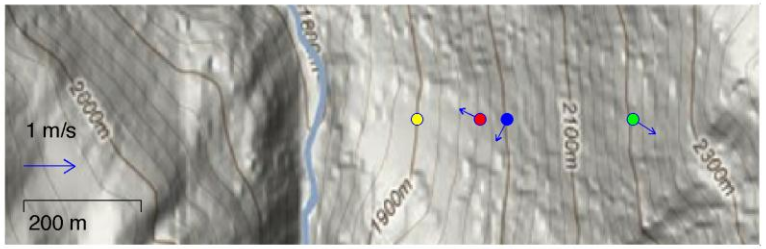

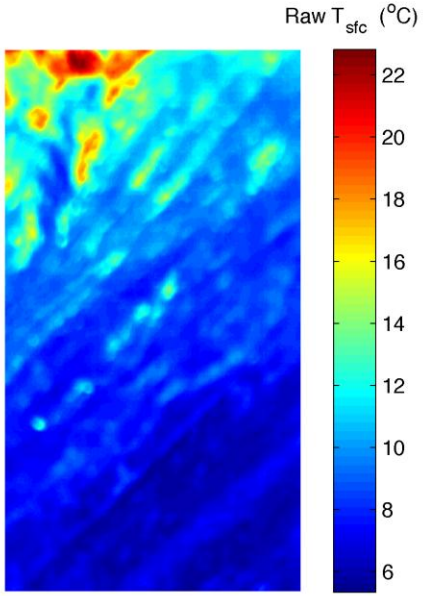

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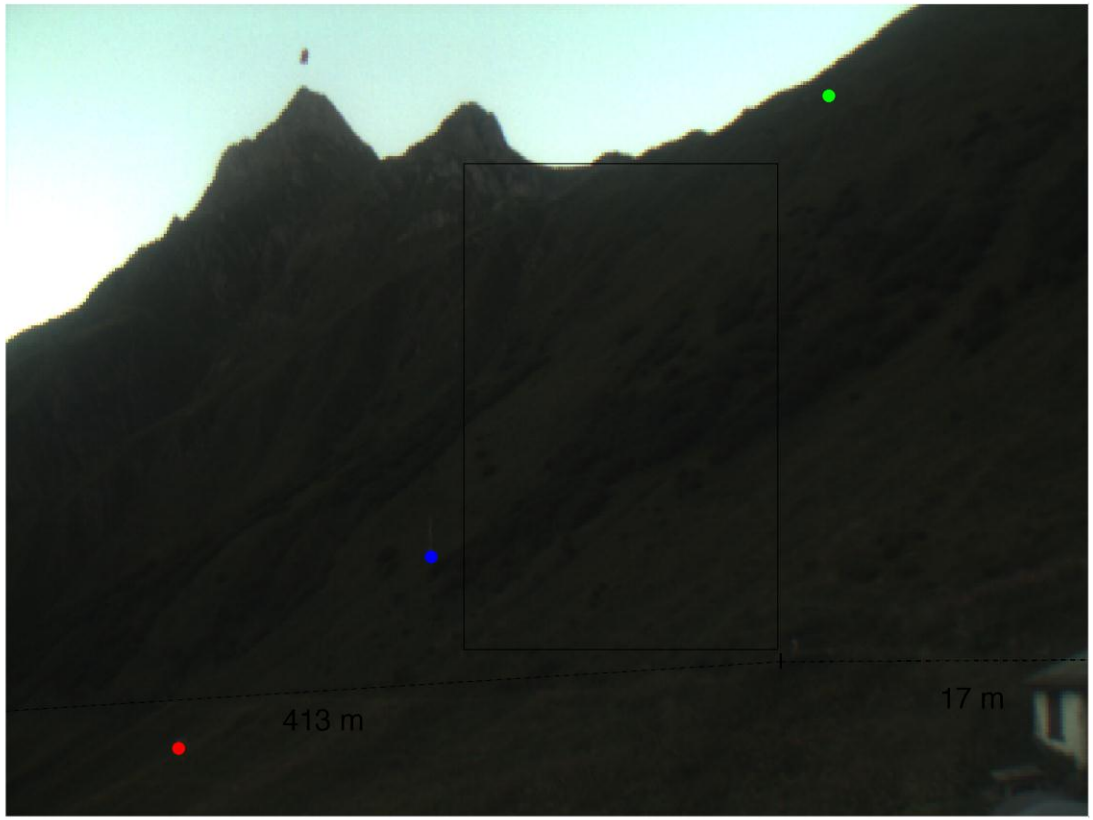
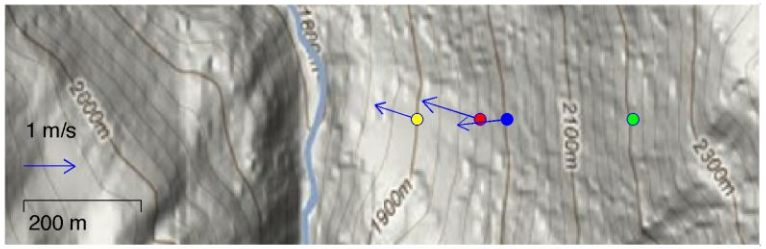
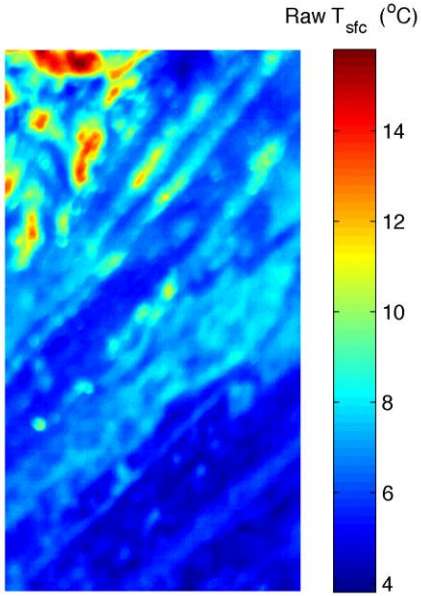
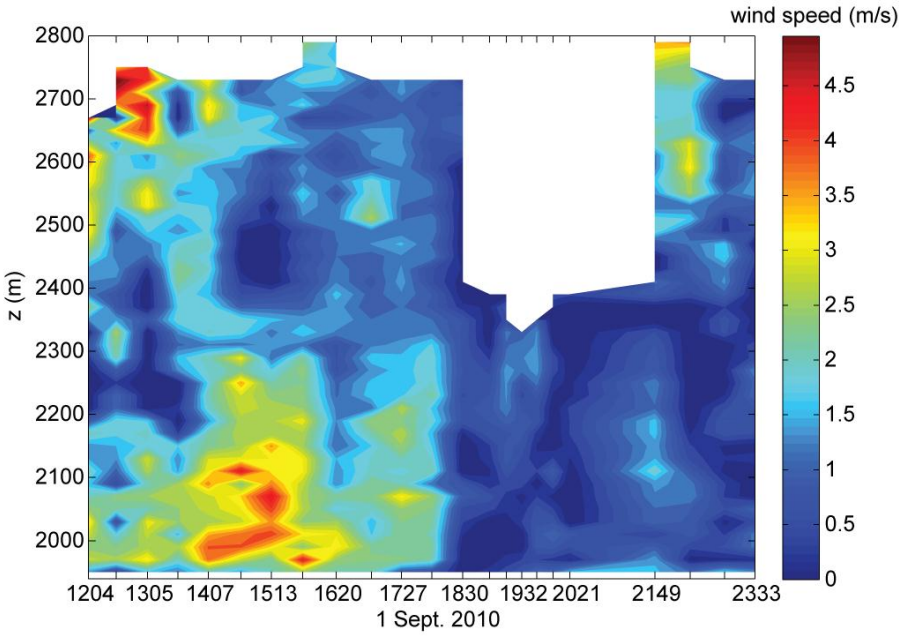






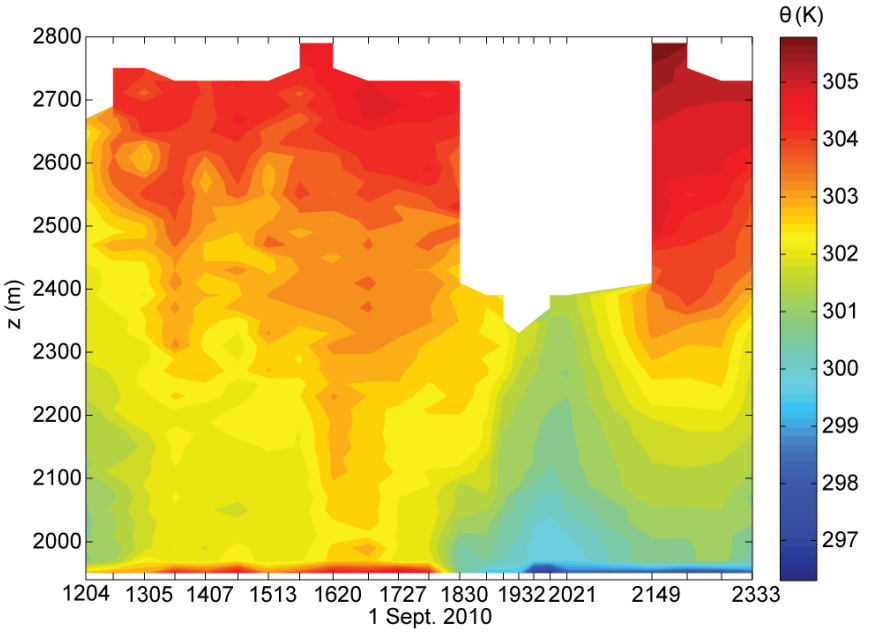
Vertical Structure of the Atmosphere

Wind speed profiles



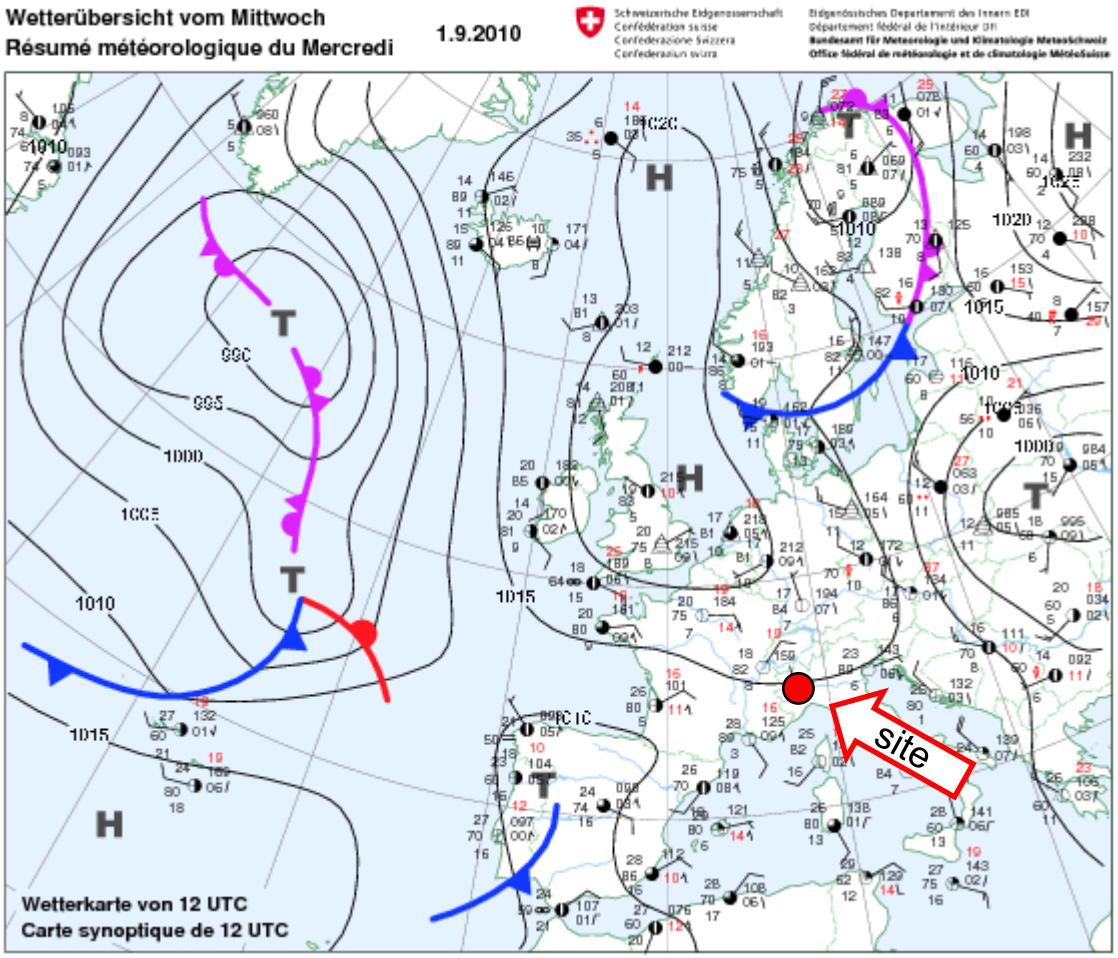
- midday upvalley wind maximum at 2050 m ASL
- calm winds for all z at evening transition
- shallow layer of downslope winds at night

Potential temperature profiles



- well-mixed daytime ABL
- h ≈ 2300 m
- mixing event at 21:00?

Weather Conditions on 1 Sept 2010

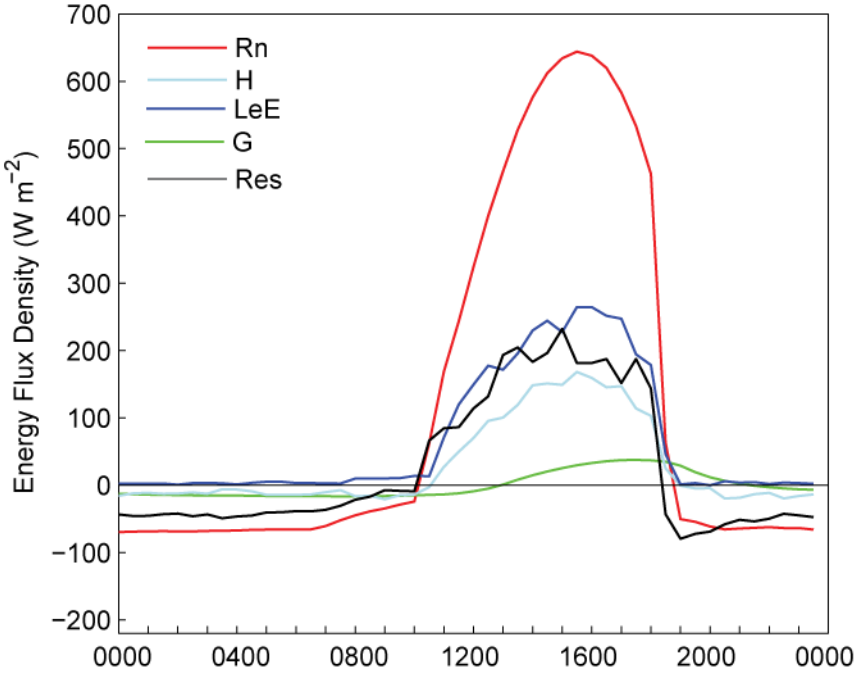


- clear sky conditions
- weak synoptic activity
- light northerly winds
- sunrise: 06:39
- sunset: 20:22
- mean daytime T_{air} = 9.1°C

field site at 13:40

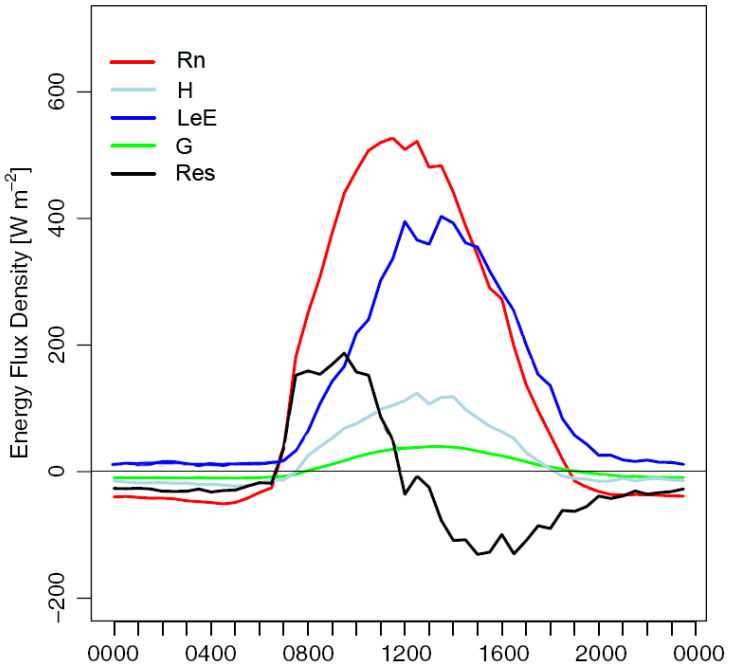
Energy Balance

Slope experiment in Val Ferret



1 Sept 2010

Crap Alv, Swiss Alps (Hiller et al., BLM, 2006)



July 2006

- daytime Bowen ratio: 0.57
- high Rn
- residuals daytime ≈ 200 W/m² / residuals nighttime ≈ -50 W/m²

plot heat storage